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Precise chronology of Polynesian temple construction and use for southeastern Maui, Hawaiian Islands determined by ^{230}Th dating of corals

Patrick V. Kirch [a, *], Regina Mertz-Kraus [b, c], Warren D. Sharp [b]

[a] Department of Anthropology, 232 Kroeber Hall, University of California, Berkeley, CA 94720, USA
[b] Berkeley Geochronology Center, 2455 Ridge Road, Berkeley, CA 94709, USA
[c] Institute for Geosciences, Johannes Gutenberg University, Mainz, Germany

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ABSTRACT

Emergent archaic states in pre-contact Hawai'i used a ritual control hierarchy implemented through a system of temples to manage production, extract tribute, and reinforce the legitimacy of the ruling elites. Based on a limited sample of precise ^{230}Th dates from coral offerings on Maui Island temples it had been hypothesized that this temple system rapidly expanded during the period from A.D. 1580–1640. We tested this hypothesis by obtaining an expanded sample of 39 new ^{230}Th coral dates from temples in Kahikinui District, and one sample from the summit of a cinder cone that likely had ritual significance. Combined with seven coral dates previously obtained, this yields a suite of 46 ^{230}Th coral dates from 26 temples in the district. Dates from both surface offerings and corals in architecturally integral contexts (placed *in situ* during temple construction) strongly agree in documenting a major phase of temple construction in Kahikinui beginning ca. A.D. 1550 and continuing until ca. A.D. 1700. The precise chronology afforded by ^{230}Th coral dating clearly resolves the timing and tempo of temple construction, shows that it corresponded closely with the reigns of Maui rulers credited in Hawaiian traditions with establishing and strengthening the first island-wide polity, and underscores the importance of monumental ritual architecture in the emergence of archaic states in ancient Hawai'i.

1. Temple chronology and archaic state emergence in ancient Hawai'i

Although classic ethnographies positioned Hawai'i within the neo-evolutionary category of "complex chiefdoms" (Sahlins, 1958; Goldman, 1970), recent advances in Hawaiian archaeology and in the interpretation of indigenous Hawaiian political history (Kirch, 2010, 2012; Hommon, 2013) indicate that four competing "archaic states" (centered on Hawai'i, Maui, O'ahu, and Kaua'i Islands) emerged within this isolated archipelago during the three centuries preceding initial European contact (A.D. 1778). Among the key transformations accompanying the emergence of these states during the late Expansion to Proto-Historic periods (ca. A.D. 1500–1800) was the development of a hierarchical system of temples associated with a pantheon of four major gods, controlled by a formal priesthood.

Archaeologically, the development of the temple system and its monumental stone architecture offers some of the strongest empirical evidence for the transition from complex chiefdom to archaic state social formations in Hawai'i (Kirch, 2010:156–165; Kolb, 1991, 1992, 1994, 2006). Hawaiian temples, or *heiau*, ranged considerably in form and function (Valeri, 1985; Kirch, 1985). Among the major indigenous categories of *heiau* were: (1) *luakini* or *po'okanaka* temples dedicated to the war god Kū, where the king performed a key cycle of annual rites; (2) *hale o Lono*, temples dedicated to Lono, god of dryland agriculture; (3) *heiau ho'o'ulu'ai*, fertility temples dedicated to either Lono or Kāne, creator god and deity of irrigated agriculture; and, (4) *ko'a*, coastal fishing shrines dedicated to Kū'ula, patron deity of fishermen. Archaeologically, temples are represented by their stone foundations, ranging from

* Corresponding author. Department of Anthropology, 232 Kroeber Hall, University of California, Berkeley, CA 94720, USA. Tel.: +510 643 8346; fax: +510 643 8557.
E-mail address: kirch@berkeley.edu (P.V. Kirch).

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small walled enclosures or platforms of a few square meters in area up to truly monumental structures such as Lo'alo'a in Kaupō, Maui, with a basal area of 4160 m^2 (Kirch, 2010, Fig. 4.10).

Determining a chronology for Hawaiian temple architecture is essential for understanding its role in archaic state emergence. Early studies of Hawaiian temples (e.g., Bennett, 1931; McAllister, 1933a, 1933b) were limited to surface mapping; in some cases temples were linked to traditional rulers whose names appear in royal genealogies. Initial attempts to excavate within *heiau* foundations sometimes revealed multiple construction episodes, with chronology dependent on radiocarbon dating (Ladd, 1969, 1973; Kolb, 1991, 1994, 2006). Kolb's seminal work on Maui temples suggested a major phase of temple construction between A.D. 1400 and 1650, a period during which population had increased and settlements expanded into dryland agricultural zones.

As is well known, however, the precision and accuracy of radiocarbon dating are limited by: (1) inherent statistical error with two standard deviation (2σ) ranges of 150–300 years for older gas-proportional dates and 40–80 years for AMS dates; (2) secular calibration problems (multiple age intercepts) which greatly complicate ^{14}C dating of samples from the last 500 years; (3) the possible incorporation of older charcoal into construction fill; and, (4) additional problems when samples have not been botanically identified and old growth wood with "in built" age may have been dated (Taylor, 1987; Spriggs and Anderson, 1993; Reith and Athens, 2013). All of these problems apply to the radiocarbon-based chronology previously developed for Hawaiian temples, such as that of Kolb (1994, 2006) for Maui Island. Of the 90 ^{14}C dates from Maui temples reported by Kolb (2006, Table 1), less than one-third were botanically identified to short-lived taxa; Kolb's sample is therefore almost certain to include a non-trivial number of specimens with an in-built age ("old wood" effect) greater than the "target event" of temple construction or use.

To avoid the problems inherent in radiocarbon dating, Kirch and Sharp (2005) applied ^{230}Th dating to branch coral dedicatory offerings from several temples in the ancient district of Kahikinui, Maui Is. U-series dating is not subject to the problems that beset radiocarbon dating, such as calibration issues. The method is more precise than radiocarbon dating, with standard error ranges of 2–10 years at two standard deviations. The initial Kahikinui coral dating results contrasted with Kolb's (1994) radiocarbon chronology, indicating that the temples had been constructed over a later and shorter period of about 60 years, between ca. A.D. 1580–1640. This compressed chronology has important implications for the emergence of an archaic state on Maui, for it corresponds with the period during which Hawaiian oral traditions relate that the king Pi'ilani, and his immediate successors Kiha-a-Pi'ilani and Kamalālāwalu, consolidated the island into a single polity (Fornander, 1878: vol 2, 87, 97–98, 121–23; Kamakau, 1961:22–33; Kirch, 2010:99–102). Royal genealogies indicate that these rulers controlled Maui between about A.D. 1570–1630 (Kirch, 2010, Table 3.1; Hommon, 2013:267). The close correspondence between this genealogically-indicated period and the U-series dates from Kahikinui temples is unlikely to be due to chance. Kirch and Sharp (2005) advanced the hypothesis that the construction of a "ritual control hierarchy" of temples was an integral part of this dynasty's strategy for consolidation of power and extraction of surplus.

Although these results were compelling, we recognized that our initial sample was limited (only seven sites were dated). Moreover, all but one of our first set of samples came from surface contexts. These points were raised by Kolb (2006), who argued that the radiocarbon corpus from Maui *heiau* supported an earlier and longer period of temple construction (see also Weisler et al., 2006). While Kolb agreed that the 60-year temple-building interval suggested by our ^{230}Th dating of corals was "intriguing," he argued that "linking these ^{230}Th dates to temple construction is problematic because near-surface coral depositions lack the stratigraphic precision of ^{14}C samples collected from basal architecture" (2006:663). To address the validity of this critique, we extended our project of ^{230}Th dating of corals, adding 39 new U-series dates (plus 4 replicates), not only from surface contexts but also from architecturally integral contexts clearly associated with temple construction. This paper presents the results of that extended study and integrates them with seven dates for Kahikinui *heiau* from Kirch and Sharp (2005), yielding a total of 46 U-series dates for corals from 26 temple sites and one date from a natural site (a cinder cone) that likely had ritual significance. We discuss these U-series dates and compare them to the calibrated age ranges for 41 radiocarbon dates now available for 31 temple sites in Kahikinui.

2. Materials and methods

2.1. Corals on Maui temple sites

The ideological significance of coral heads or branches broken off of coral heads (primarily from the species *Pocillopora meandrina*) is not well understood in Hawaiian ethnohistory. Nonetheless, it is certain that corals had ritual significance in a number of Polynesian societies (Rowland, 2007); for example, coral blocks were incorporated into the facades of temple altars in the Society Islands (Sharp et al., 2010). For Hawai'i, the nineteenth-century Hawaiian author Malo (1951:175) describes a rite associated with the *luakini* or king's war temple, during which the participants purified themselves by bathing in the ocean, then "carried with them pieces of coral, which they piled up outside of the *heiau*" (see also Handy, 1927:281; Valeri, 1985:319). Archaeological evidence documents the presence of branch corals on many types of temples, including agricultural temples (*heiau ho'o'ulu'ai*) and fishing shrines (*ko'a*). The Hawaiian word *ko'a* is polysemic, with glosses of "coral," "fishing grounds," and "fishing shrine" (Pukui and Elbert, 1986:156). There are hints in Hawaiian mythology that coral was associated with the creator god Kāne (Beckwith, 1940:59; 1951:55, 58). Sun-bleached coral, turning pure white, may also have been associated with Lono, among whose ritual symbols were white barkcloth streamers and white bird skins (Valeri, 1985:15).

Corals occur on Maui temple sites (1) in surface contexts and (2) incorporated within architectural elements such as stacked stone walls or platforms; samples collected from the latter context are referred to herein as "architecturally integral." The surface samples often occur on temple altars, on top of walls, or on pavements, where they appear to have been placed either as dedicatory offerings, or as ritual offerings during temple use. The architecturally integral samples are from wall fill (exposed through wall collapse), or from beneath the basal stones of walls. Whereas the surface samples could have been placed on the altars or pavements anytime during temple use, the architecturally integral samples were sealed *in situ* and securely date wall construction. While we cannot entirely exclude the possibility that corals were occasionally re-used, the high degree of consistency between multiple dates from individual sites (see Section 3.3) argues against this being a major problem.

A key criterion for archaeological dating is that the "death age" of the sample corresponds closely to the "target event" to be dated, in this case the placement of the coral offerings (Dean, 1978). All of the coral samples used in our study were examined for the preservation of delicate surface structures (verrucae) which rapidly wear away in an erosional environment such as a beach. Most of the specimens lack any visible abrasion or erosion indicating that they were collected as live specimens prior to their placement in temple contexts; a few specimens, identified in Table 1, exhibited minor

Table 1
Sample descriptions, ^{230}Th dates, and selected U–Th analytical data for archaeological corals from Kahikinui and Kaupō temple sites. Uncertainties are 95% confidence intervals, all isotopic ratios are activity ratios, ^{230}Th and ^{234}U decay constants are those of Cheng et al. (2000). Uncorrected dates are not corrected for initial ^{230}Th. Corrected dates are corrected for initial ^{230}Th assuming $(^{230}Th/^{232}Th)_{initial} = 1.25 \pm 0.63$. Samples designated -R are replicates. Samples previously reported by Kirch and Sharp (2005) are indicated by italics.

Sample no.[a]	Description	Context[b]	Provenience	^{232}Th pg/g	^{230}Th/^{232}Th AR	Uncorrected date (A.D.)	Corrected date (A.D.)
AUW-6-CS2	Branch, intact tips	AI	Built into base of outer wall	100	360.4	1546 ± 1.6	1547 ± 2
AUW-9-CS1	Branch, intact tips	S	On floor, near base of old wall	113	212.5	1694 ± 1.6	1696 ± 2
AUW-9-CS1-R	Branch, intact tips	S	On floor, near base of old wall	100	240.4	1695 ± 2.6	1697 ± 3
AUW-9-CS2	Branch, intact tips	AI	In stones from collapsed old wall	124	187.1	1696 ± 1.7	1698 ± 2
AUW-9-CS2-R	Branch, intact tips	AI	In stones from collapsed old wall	111	206.1	1696 ± 2.4	1698 ± 3
AUW-9-CS3	Branch, intact tips	AI	Under base of old wall	126	197.1	1690 ± 2.2	1692 ± 2
AUW-9-CS3-R	Branch, intact tips	AI	Under base of old wall	105	236.2	1688 ± 9.9	1690 ± 10
AUW-9-CS4	Branch, slightly rounded	AI	In collapsed wall of new platform	143	189.8	1669 ± 1.8	1671 ± 2
AUW-9-CS6	Branch	AI	In old wall exposed by collapse	156	158.9	1692 ± 3.0	1694 ± 3
AUW-9-CS6-R	Branch	AI	In old wall exposed by collapse	137	173.6	1691 ± 9.5	1693 ± 10
AUW-11-CS1	Branch sawed from coral head	S	On altar	742	22.6	1747 ± 4.0	1762 ± 9
AUW-11-CS2	Branch	AI	In east wall, amid loose stones	275	69.6	1750 ± 1.9	1755 ± 3
AUW-11	Branch fragment	S	On altar	284	119.9	1629 ± 4	1638 ± 6
WF-AUW-338-CS1	Branch, some broken tips	S	Set in between paving stones of terrace, near entrance	316	162.8	1322 ± 2.1	1328 ± 3
WF-AUW-359 CS2	Branch, intact tips	S	Wedged between pavement stones 3 m W of E wall	150	165.8	1709 ± 3.0	1712 ± 3
WF-AUW-359 CS3	Branch, intact tips	S	Set between stones on N wall	138	222.7	1586 ± 3.5	1588 ± 4
AUW, Pu'u Hoku Kano-CS1	Branch, rounded tips	S	Collected from summit of cinder cone, near the USGS benchmark	274	146.5	1553 ± 1.9	1557 ± 3
LUA-3-CS2	Branch, slightly rounded	S	On floor	134	241.3	1588 ± 2.1	1590 ± 2
LUA-4-CS1	branch, slightly rounded	S	On top of wall	165	164.2	1694 ± 1.2	1696 ± 2
LUA-29-CS1	Branch, intact tips	AI	In partly collapsed wall of small enclosure	297	121.0	1610 ± 1.7	1615 ± 3
LUA-29-CS4	Branch, intact tips	AI	In wall of small enclosure	133	225.1	1656 ± 1.3	1658 ± 2
LUA-29-CS6	Branch, intact tips	AI	In partly collapsed wall of large enclosure	103	255.1	1658 ± 1.9	1660 ± 2
LUA-36-CS1	Small coral head	S	Interior base of wall	154	200.8	1654 ± 2.2	1656 ± 3
ALE-4-CS1	Branch, rounded tips	S	From floor fill	366	97.2	1549 ± 2.6	1555 ± 4
ALE-121-CS2	Branch, intact tips	AI	In wall	220	116.1	1696 ± 1.6	1699 ± 2
ALE-140-CS1	Small branch with tip from coral head	S	On wall	232	152.6	1589 ± 2.3	1592 ± 3
KIP-1-CS1	Slightly rounded	S	Base of south wall	273	223.7	1321 ± 2.8	1325 ± 3
KIP-273-CS2	Branch	S	Upper U-shaped enclosure	273	101.4	1624 ± 2.6	1629 ± 4
KIP-273-CS4	Branch, intact tips	AI	Under fill blocks, lower notched *heiau*	176	145.4	1666 ± 2.7	1669 ± 3
KIP-273	Branch tip	S	On pavement	231	139.2	1610 ± 6	1618 ± 7
KIP-275	Branch fragment	S	On paved surface of platform	194	133.5	1617 ± 5	1625 ± 6
KIP-306-CS1	Branch, intact tips	AI	Lodged under top layer of rocks	202	155.3	1592 ± 3.0	1595 ± 4
KIP-306-CS3	Branch, intact tips	S	In between paving stones	264	118.7	1574 ± 1.8	1579 ± 3
KIP-307-CS2	Branch, intact tips, cut from larger piece	AI	Under enclosure wall	246	108.6	1643 ± 1.9	1647 ± 3
KIP-307-CS1	Small branch, intact tips	AI	Under enclosure wall	179	155.0	1640 ± 2.2	1643 ± 3
KIP-330-CS1	Branch, intact and some rounded tips	S	Large coral head 1	252	110.3	1653 ± 1.9	1658 ± 3
KIP-330-CS3	Branch, intact tips	S	Large coral head 3	138	160.3	1731 ± 1.2	1733 ± 2
KIP-405	Branch tip	S	On altar	249	147.2	1594 ± 6	1601 ± 7

Table 1 (*continued*)

Sample no.[a]	Description	Context[b]	Provenience	^{232}Th pg/g	^{230}Th/^{232}Th AR	Uncorrected date (A.D.)	Corrected date (A.D.)
KIP-414	Branch, broken and rounded tips	S	On enclosure wall	268	155.2	1571 ± 2.1	1574 ± 3
KIP-414	Colony base fragment	S	On enclosure wall	76	306.7	1569 ± 5	1574 ± 6
KIP-567	Branch, intact tips	S	Branch coral from pit	189	170.9	1571 ± 2.0	1574 ± 3
KIP-728-CS1	Branch, intact tips	AI	Excavated, unit Q26 level 1 obj#10	140	231.5	1570 ± 3.8	1572 ± 4
KIP-728-CS2	Branch, intact tips	AI	Excavated, unit Q25 level 4 obj#1	147	250.6	1570 ± 3.8	1572 ± 4
KIP-1010	Colony base fragment	S	On pavement near entryway	115	241.6	1574 ± 10	1580 ± 10
NAK-29-CS3	Branch, broken tips	AI	Exposed in collapse of SW corner of the lower terrace, in construction context	242	119.5	1599 ± 1.5	1603 ± 3
MAW-255	Branch tip	AI	Excavated *in situ* from wall base	350	108.1	1619 ± 5	1629 ± 7
KOU-CS-1	Branch, rounded tips	S	Platform in front of altar	143	127.6	1777 ± 5.1	1779 ± 5
KOU-CS-2	Branch, some broken and rounded tips	S	Top of altar wall, exposed in slight collapse, hence probably originally in fill	173	94.6	1791 ± 3.6	1794 ± 4
KOU-CS-3	Branch, intact tips	S	Large lobe on top of first terrace face of main altar; weathering suggests *in situ* for long period	811	40.2	1622 ± 6.3	1634 ± 9
KOU-CS-4	Branch, intact tips	AI	Exposed in partial collapse of north wall, hence was originally in wall fill; similar context to KOU-CS-5a	474	98.0	1388 ± 5.9	1396 ± 7
KOU-CS-5a	Branch, broken and slightly rounded tips	AI	Exposed in collapsed segment of the north wall, originally in wall fill; similar context to	324	231.2	1094 ± 7.5	1099 ± 8

[a] Codes for territories within the Kahikinui and Kaupō districts are as follows: AUW = Auwahi; WF-AUW = Auwahi windfarm project area; LUA = Luala'ilua; ALE = Alena; KIP = Kipapa and Naka'ohu; NAK = Naka'aha; KOU = Kou (Kaupō).
[b] Context: S = surface; AI = architecturally integral.

wear of the branch tips. Moreover, since *P. meandrina* exhibits growth rates on the order of 0.5–1 cm/yr, it was possible to isolate dating samples weighing ~0.2 g that formed within 1–2 years of coral death. Thus the death ages and the target event ages are expected to be essentially identical for the corals in our sample.

We recognize that there is always a slight possibility that a few of the corals collected by the Hawaiians for use as offerings were already dead at the time of their acquisition, but still adhering to rocks in the ocean. In that case, the accumulation of some Th in the dead coral could produce a minor in-built age effect, analogous to the problem of dating old wood with radiocarbon. However, given the extremely high energy geomorphological environment of coastal Kahikinui (with a complete absence of protective reefs, corals simply adhering to exposed basalt substrates) we consider it implausible that deal corals would remain for any length of time.

2.2. Field sampling of coral architectural elements

Fifty-nine temple sites (*heiau* and *ko'a*) had previously been located and recorded by Kirch over twelve years of field research in Kahikinui. Not all *heiau* exhibit corals, and those that do are more commonly in coastal than inland locations, but 26 sites where corals were known to occur were visited and sampled for this study (Fig. 1). The locations of coral samples were determined with a Trimble GeoXT GPS unit, marked on site maps, and photographed *in situ* (Fig. 2). When possible, we obtained both surface and architecturally integral samples from the same temple. Samples were either taken whole, or were cut from larger coral heads with a portable Makita rotary saw and placed into sterile plastic bags. Samples were cut from branch tips of *Pocillopora* corals wherever possible to minimize in-built age.

2.3. U-series dating of corals

Analyses were performed at the Berkeley Geochronology Center using a Thermo NEPTUNE *Plus* Multi-Collector-Inductively-Coupled-Mass-Spectrometer (MC-ICP-MS). Internal pieces of coral were isolated by breaking, sawing, and abrading with a tungsten carbide bit, then cleaned by repeated cycles of ultrasonic treatment and rinsing in de-ionized water. Samples weighing ~200 mg were totally dissolved in 7 N HNO_3 and equilibrated with a mixed spike containing ^{229}Th, ^{233}U, and ^{236}U. The spike was calibrated against solutions of NBL CRM 145 and solutions prepared from a 69 Ma U ore that has been demonstrated to yield concordant U/Pb ages (Schwartzwalder Mine, Colorado, USA; hereafter, SM; Ludwig et al., 1985) and sample-to-sample agreement of ^{234}U/^{238}U and ^{230}Th/^{238}U ratios. U and Th were separated using two stages of HNO_3–HCl cation exchange chemistry followed by reaction with HNO_3 and $HClO_4$ to remove any residual organic material. Coral analyses were corrected for ^{230}Th blanks of 0.00035 ± 0.0002 fmol,

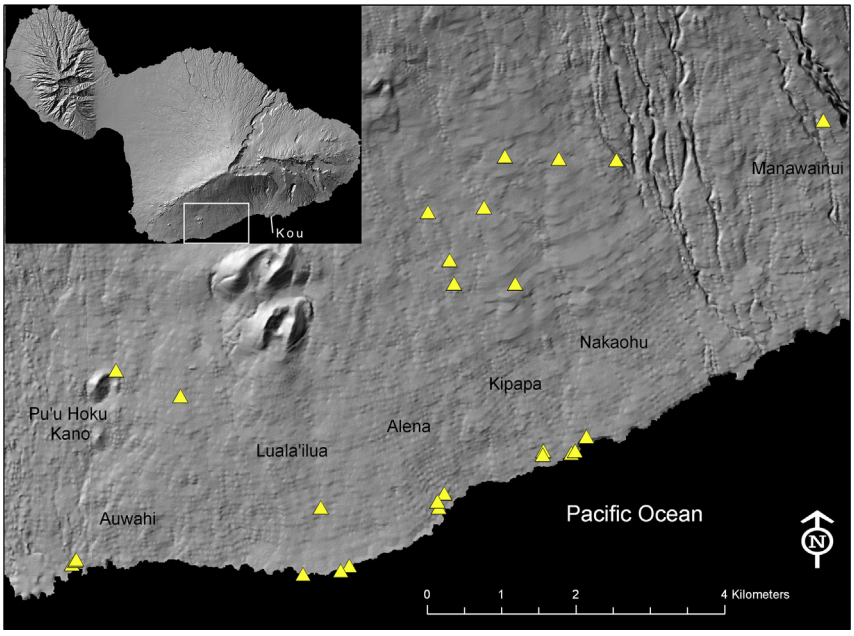

Fig. 1. Map of southeastern Maui showing the ancient districts of Kahikinui and Kaupō, with the locations of temple sites sampled for this study.

which introduce an age error of <0.5 yr. MC-ICP-MS analyses followed the procedures outlined in Mertz-Kraus et al. (2012). Measured peak heights were corrected for multiplier dark noise/Faraday baselines, background intensities, ion counter yields, tail contributions, and interfering spike isotopes. Mass fractionation was determined using the gravimetrically determined $^{233}U/^{236}U$ ratio of the spike. The external reproducibility of $^{234}U/^{238}U$ and $^{230}Th/^{238}U$ ratios of SM solutions measured during each mass spectrometry session was better than 0.2%. Ages were calculated using the half-lives of Jaffey et al. (1971) for ^{238}U, Holden (1990) for ^{232}Th, and Cheng et al. (2000) for ^{230}Th and ^{234}U. Corrected dates are corrected for initial ^{230}Th assuming $(^{230}Th/^{232}Th)_{initial,\ atom\ ratio} = 6.8 \pm 3.4 \times 10^{-6}$. Age uncertainties are stated at the 2σ level and include measurement uncertainties as well as uncertainties associated with the initial isotope correction.

Fig. 2. Coral head *in situ*, on the northern wall of site ALE-140, a small notched *heiau* at Wailapa, Alena, Kahikinui. The coral head is approximately 20 cm in diameter. (Photo by P. V. Kirch).

3. Results

Table 1 presents sample descriptions, provenience and context data, ^{230}Th dates, and selected U–Th analytical data for 40 newly dated coral samples (including four replicates from site AUW-9) along with seven previously dated samples from 26 temple sites and from the summit of one volcanic cinder cone. Complete U/Th analytical data for the newly reported dates are presented in Table S1 (available on-line). Samples are grouped by the territories where the temples are located, from west to east. All but one of the temple sites are located within Kahikinui district, while one (Kou *heiau*) lies in Kaupō district. This represents a 44 percent sample of known *heiau* within Kahikinui.

3.1. Temporal distribution of coral dates

Fig. 3 plots all 46 coral dates (excluding the four replicates) by 50-year age intervals, combined with a plot of the cumulative probability distribution of the dates. Four dates are significantly earlier than the others, one falling into the A.D. 1050–1099 bin, two into the A.D. 1300–1349 bin, and one into the A.D. 1350–1400 bin; the possible significance of these early dates is addressed below (see Section 3.3). The other 42 dates fall in the period from A.D. 1500–1799. Especially striking is the spike in the number of dates during the 150-year long period between A.D. 1550 and 1699. Thirty-five dates, representing 76 percent of all dated samples, fall into this period.

Fig. 4 plots the temporal frequency of temples ($N = 26$) dated by the coral samples, again using by the same 50-year age intervals and again combined with a plot of cumulative probability distribution. For this figure we use only the oldest date for each temple (i.e., that most closely approaching initial construction), so that each temple site is indicated only once on the chart. Fig. 4 is therefore a plot of temple construction dates, rather than a plot of the temple use span. In this case, the spike between A.D.

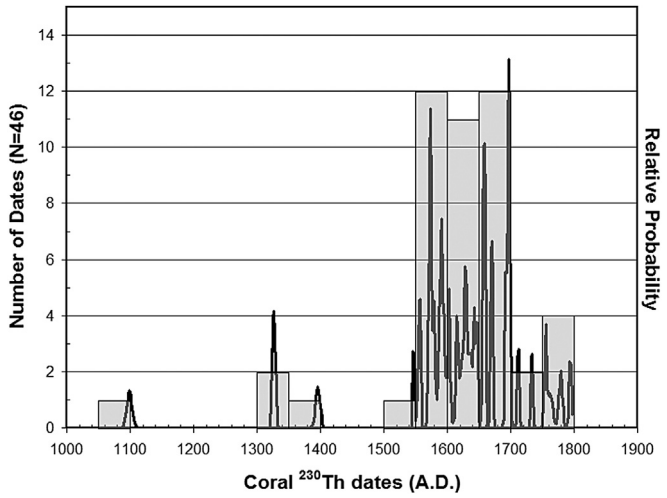

Fig. 3. Frequency histogram of corrected dates of coral samples from southeastern Maui temple sites ($N = 46$), plotted by 50-year age intervals combined with a plot of the cumulative probability distribution of the dates.

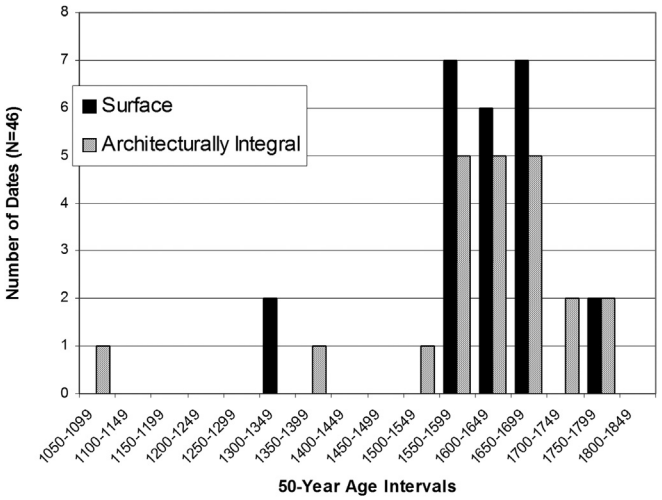

Fig. 5. Frequency distribution of coral dates derived from surface versus architecturally integral contexts, plotted by 50-year age intervals.

1550–1599 (with nine temples constructed) is especially clear, followed by the construction of eight more temples between A.D. 1600–1649, and another five temples between A.D. 1650–1699. In all, 22 of the 26 temples, or 85 percent, were constructed during the 150 year period between A.D. 1550 and 1699.

3.2. Surface versus architecturally integral samples

Our expanded sample of coral dates obtained from both surface and architecturally integral contexts also us to test whether the two contexts yield different temporal distributions. As noted earlier, the initial dates published by Kirch and Sharp (2005) came, with a single exception, from surface samples; Kolb (2006:663) argued that this might have led to a bias toward younger dates.

Our enlarged sample of 46 coral dates includes 24 from surface contexts and 22 from architecturally integral contexts. Fig. 5 shows the distribution of these two subsets using the same 50-year intervals as in Figs. 3 and 4. The two subsets display nearly identical patterns; regardless of whether one uses the surface or architecturally integral subset, the same major phase of temple construction and use between A.D. 1550–1699 is evident. Of the four early dates, two are from surface contexts, and two from architecturally integral contexts. Both subsets show continued temple use into the period from A.D. 1750–1799. In short, no significant bias is introduced when corals from surface contexts are used to infer the timing of Kahikinui temple construction. It follows that most surface corals in Kahikinui *heiau* are indeed dedicatory offerings, as suggested by Kirch and Sharp (2005). Moreover, given the consistency between the two subsets, the use of a combined total sample (as in Fig. 3) is justified.

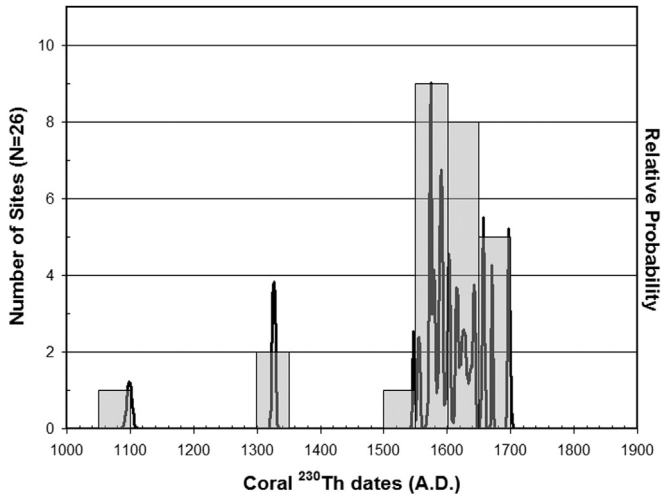

Fig. 4. Frequency histogram of oldest dates from temple sites ($N = 26$) dated by coral samples from southeast Maui, plotted by 50-year age intervals, combined with a plot of the cumulative probability distribution.

3.3. Temple sites with multiple dates

In our sampling we attempted to obtain two or more coral samples from the same temple whenever possible, in order to assess the extent to which samples from the same structure would agree or overlap in age, or possibly indicate longer use spans for the site. Here we discuss sites with two or more coral samples. Where available, we also discuss radiocarbon dates obtained from these sites, as they illustrate the problems inherent in the use of radiocarbon for determining temple chronology.

3.3.1. Site AUW-9

This coastal temple exhibits complex architecture, with evidence for two phases of construction: an earlier phase during which a classic "notched" type of enclosure was constructed (a temple form having six sides), followed by a phase when part of the notched wall was removed and a high platform constructed on the seaward side of the enclosure. Five samples of branch coral from AUW-9 were dated. Replicate analyses of four of these corals were also performed, all with very good agreement (Table 1). Sample CS-6 came from within the main wall fill in a small collapsed area; the coral had been placed within the wall during construction. The dates are highly consistent, falling in the decade from A.D. 1690–1698, with a single exception. The outlier is sample CS-4 which came from the collapsed fill of the platform, and yielded an age of A.D. 1671 ± 2 years. However, this specimen was slightly water-rounded, probably having been collected from the nearby beach; it therefore is likely to have some in-built age.

During test excavations at AUW-9, Kirch obtained charcoal (identified as *Chamaesyce* sp., a short-lived taxon) from the basal

level of the cultural deposit within the temple enclosure. The AMS radiocarbon date (Beta-183146) has a conventional age of 390 ± 40 B.P., with two possible calibrated age ranges, of A.D. 1430–1530 and 1540–1640 (2σ), all earlier than the suite of five coral dates. Because the charcoal sample is of a short-lived species there is no expectation of an in-built age problem. However, the sample cannot be directly associated with the stone architecture, as it came from the base of a cultural deposit which may predate *heiau* construction. The charcoal presumably derives from cultural activity on the site prior to wall construction. This example illustrates the problem with radiocarbon dates from cultural deposits within *heiau*, especially those identified as being "basal" (as with many of the dates reported by Kolb [2006, Table 1]).

3.3.2. Site AUW-11

This small, high walled enclosure situated a few meters away from AUW-9 functioned as a *ko'a* or fishing shrine (based on the presence of an upright, waterworn Kū'ula stone within the enclosure). Two branch coral specimens were dated. Sample AUW-11-CS-1 is a branch removed from an entire *Pocillopora* coral head lying on the court floor next to the stone upright; this yielded a corrected date of A.D. 1762 ± 9. Sample AUW-11-CS-2 is an architecturally integral specimen extracted from the inner face of the north wall where it had been wedged in a cavity between wall stones, probably during construction. This sample yielded a corrected date of A.D. 1755 ± 3.

A single radiocarbon date is also available for AUW-11, a sample of *Chamaesyce* sp. charcoal from Level 4 of a test pit within the enclosure (Beta-183147), yielding a conventional age of 160 ± 40 B.P. with calibrated age ranges of A.D. 1660–1890 and 1900–1960 (2σ). While the radiocarbon date overlaps with the two coral dates, the latter provide a more precise indication of the age of construction.

3.3.3. Site WF-AUW-359

For this small, notched temple in the Auwahi uplands we dated two coral samples, both from surface contexts. Sample CS-1 yielded a date of A.D. 1712 ± 3, while sample CS-2 yielded a date of A.D. 1588 ± 4. In this case the coral dates, both for surface samples, do not overlap, suggesting that offerings were made at this temple over a period of more than a century.

3.3.4. Site KIP-330

This *ko'a* or fishing shrine in Kipapa has several large *Pocillopora* coral heads placed on its walls and interior pavement, as offerings. We removed branch tips from two of the coral heads for dating, with resulting dates of A.D. 1658 ± 3 (CS1) and 1733 ± 2 (CS3). Both of these are from surface contexts, and as with site WF-AUW-359 (see Section 3.3.3) indicate a considerable period (in this case about 75 years) during which offerings were made at this shrine.

3.3.5. Site LUA-29

Detailed mapping of this notched *heiau* situated near the coast at Hanamauloa demonstrated that it was constructed in two distinct phases (Fig. 6). The smaller room or enclosure on the temple's western side does not open onto the main court in the eastern enclosure, as would be the case in most notched *heiau*. This is because the western enclosure was apparently a *ko'a* or fishing shrine which existed as a free-standing structure prior to the addition of the larger eastern enclosure, turning the combined structure into a notched temple.

Site LUA-29 provided an excellent opportunity to see whether coral dating of samples from the two different parts of the structure would correspond to the construction sequence indicated by our mapping. Three coral samples were dated. Sample LUA-29-CS-1 was embedded within the wall stones at the southwest corner of the western enclosure (the putative earlier *ko'a*), presumably placed there during construction. It yielded a corrected date of A.D. 1615 ± 3. LUA-29-CS-4 is a small branch tip which was tightly embedded in the wall at the junction of the northeast corner of the *ko'a* with the abutted eastern enclosure, placed there when the eastern enclosure was added. This sample yielded a corrected date of A.D. 1658 ± 2. The third dated sample, LUA-29-CS-6, is a branch tip embedded in the eastern wall of the eastern enclosure; it had to be "excavated" out by removing some wall stones and clearly was a part of the original wall construction. This sample yielded a corrected date of A.D. 1660 ± 2 years at 2-sigma, nearly identical with CS-4. The architecturally-integral branch coral dates from LUA-29 all should date to the time of wall construction. The date of A.D. 1612–1618 from the *ko'a* or smaller western enclosure indeed confirms that this part of the structure was built about 45 years before the eastern enclosure was added, in ca. A.D. 1656–1662.

3.3.6. Site KIP-273

This coastal temple consists of two structural components, a notched enclosure and a platform with a low, U-shaped wall. We dated one coral sample from each component: KIP-273-CS2 came from the platform surface and yielded a date of A.D. 1629 ± 4, while KIP-273-CS4 came from under fill blocks in the notched enclosure, with a date of A.D. 1669 ± 3. These dates suggest that the platform was built first, with the notched enclosure added about forty years later.

3.3.7. Site KIP-307

This coastal temple was originally constructed as a notched *heiau* whose walls were then partially removed and reconstructed as a house site in the post-contact era. We recovered sample KIP-307-CS-1, a branch tip in excellent condition, and sample KIP-307-CS-2, a large multi-lobed branch with intact base, from under basal stones in the western wall of the notched enclosure, in architecturally integral contexts. The consistent dates of A.D. 1647 ± 3 and 1643 ± 3 allow a precise estimate of initial wall construction for this notched temple.

3.3.8. Site KIP-306

Site KIP-306 is a small *ko'a* or fishing shrine in Kipapa. Sample KIP-306-CS-1, from the northern wall, yielded a corrected date of A.D. 1595 ± 4. A second sample, KIP-306-CS-3, was collected from between paving stones of the upper terrace, and yielded a corrected date of A.D. 1579 ± 3 years. Although there is a slight difference in ages of these two samples, they are reasonably consistent in indicating a late sixteenth century date for shrine construction.

3.3.9. Site KIP-728

This is a large temple of the elongated, double-court type situated in the Kipapa uplands. The two dated coral samples were obtained by Kirch during excavations of the subsurface deposit; they were associated with an original pavement of lava slabs. Both samples returned identical dates of A.D. 1572 ± 4 years.

3.3.10. Kou heiau

This temple, situated near the coast in Kaupō district, is by far the largest in our sample and likely served as a *luakini* or war temple for human sacrifice. It consists of an elongated U-shaped enclosure defined by 3-m high walls on the north and south, and a 3.6-m high double-terraced eastern wall which presumably was the main altar. The main enclosure with its court open to the west is roughly 70 m long by 26 m wide. Based on measured cross-sections through the enclosing walls, we estimated that the structure incorporates at least 1614 m^3 of stone fill.

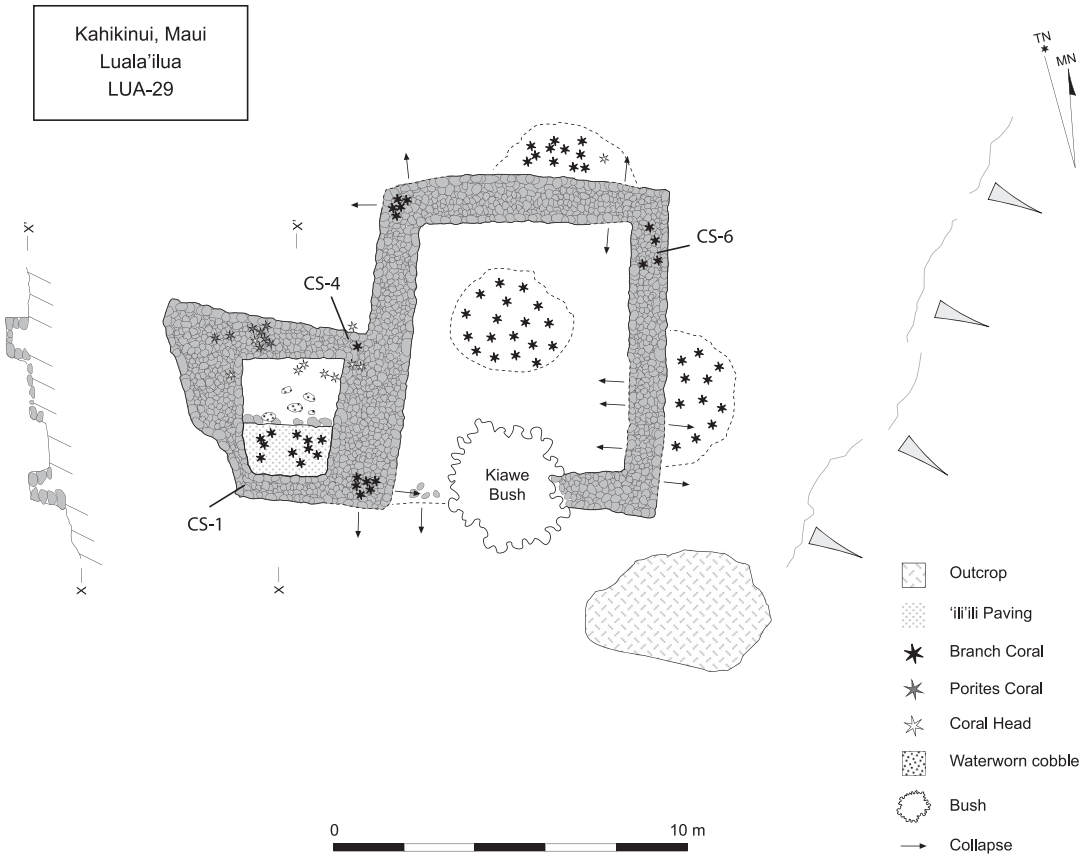

Fig. 6. Plan of site LUA-29, consisting of two contiguous stone walled enclosures. The positions of dated coral samples (CS-1, -4, and -6) are indicated.

Oral traditions do not link Kou to any specific Maui ruler; however, king Kekaulike (ca. A.D. 1710–1730) made Kaupō his royal seat and constructed two other large temples (Lo'alo'a and Popoiwi) in the district (Kamakau, 1961); he may well have conducted ceremonies at Kou. Kou does figure prominently in Hawaiian oral traditions of the earliest period of Polynesian arrivals in Hawai'i: Kamakau (1991:112) refers to the arrival of Kāne and Kanaloa from Kahiki (Tahiti) and how they discovered the freshwater source at Kou (probably the nearby spring of Waiū).

We collected and dated five coral samples from Kou, three from surface contexts and two from architecturally integral contexts (Table 1). The resulting dates give the longest time span for any site in our sample, including two of the four corals pre-dating the major period of temple building that began ca. A.D. 1550. These two early dates both came from collapsed segments of the temple's northern wall, where they were part of wall fill. KOU-CS-5a yielded a date of A.D. 1099 ± 8 while KOU-CS-4 has a date of A.D. 1396 ± 7. Although nearly three centuries apart, both samples come from the same architectural context. In this case, it is unlikely that either sample actually dates the time of construction of the massive northern wall. Rather, Kou presumably had been a locus of ritual activity from a very early time (as referenced in the oral tradition), during which coral offerings were made. When the northern wall was constructed, a large quantity of lava rubble had to be collected and heaped up as wall fill, presumably incorporating these and other pieces of coral which were already present on the site. This demonstrates the complications that can arise with complex, monumental architecture on a site used over an extended time period.

The three surface context samples suggest a relatively late age for the main temple architecture. Sample KOU-CS-3, with a date of A.D. 1634 ± 9, comes from the main altar platform, which therefore probably dates to the early 17th century, coincident with the reigns of either Kamalālāwalu or Kauhi-a-Kama, two Maui rulers preceding Kekaulike. Samples KOU-CS-1 and KOU-CS-2 have dates of A.D. 1779 ± 5 and 1794 ± 4, respectively. These indicate very late continued use of the temple, into the period following initial European contact (A.D. 1778). This period was notable for inter-island warfare between the Maui and Hawai'i kingdoms, with several major battles occurring at Kaupō (Kamakau, 1961). Continued offerings at a major war temple such as Kou during this period is consistent with the historical record.

3.4. Coral offering on Pu'u Hoku Kano cinder cone

In addition to the coral samples from temple sites, we dated a sample of branch coral from the summit of a prominent cinder cone, Pu'u Hoku Kano, situated in Auwahi *ahupua'a* (Fig. 1). Prominent topographic features such as cinder cones were often regarded as places of spiritual importance in traditional Hawaiian religion, where rituals and offerings were at times conducted. Exploring the summit of this cinder cone, which looms prominently over the western Kahikinui landscape, we were intrigued to find several pieces of branch coral, partly buried in the volcanic cinders. Surmising that these had been deposited here as ritual offerings, we dated one sample which yielded a corrected date of A.D. 1557 ± 3 years. This date falls in the 50-year interval immediately prior to the main phase of temple construction in Kahikinui (Figs. 3 and 4).

3.5. Temple morphology, orientation, location, and time

The high-precision dating of a large number of the known temple sites in Kahikinui district provides an opportunity to test whether differences in temple architecture (morphology), temple orientations, or temple geographic locations display temporally meaningful patterns. Table 2 presents data relevant to these topics for all of the non-*ko'a* (fishing shrine) sites. In Table 2 the temples are ordered by the oldest coral date for each site; in the case of Kou we use the KOU-CS-3 date from the main altar as this seems to best represent the age of the standing architecture.

Kirch (2004) demonstrated that the *heiau* of Kahikinui fall into three main morphological categories: (1) notched temples, with six-sided enclosure walls; (2) square enclosures; and (3) elongated, double-court temples. The data presented in Table 2 demonstrate that the notched form is present throughout the entire sequence. The square enclosure form is less well represented, with only three sites, but spans a period from A.D. 1575 to 1625. Only two elongated, double-court temples are present in the sample, and both are relatively early in the sequence, although the very old sample from KIP-1 (a surface context) may represent the re-deposition of an older coral offering, rather than actual construction. Nonetheless, it is possible that the elongated, double-court *heiau* type is relatively early in the Kahikinui sequence.

The orientation of *heiau* (i.e., the direction faced by the temple's main axis, with the altar at one end) has been shown to be non-random (Kirch, 2004), with three principal orientations, arguably associated with the three principal deities of Kū (north), Lono (northeast), and Kāne (east). There is no clear temporal ordering in the orientation data presented in Table 2, all three orientations being represented over time.

Finally, we considered the geographic position of temples, whether situated close to coast or in the uplands (where most of the population and agricultural activities were concentrated). While both coastal and inland temples appear early, there is a main phase between A.D. 1572 and 1603 when eight inland temples were constructed, and only a single coastal temple. This is consistent with the settlement pattern of Kahikinui district, in which the main zone of permanent habitation and farming was in the uplands between about 400 and 600 m above sea level, where rainfall was sufficient to grow sweet potatoes and dryland taro (Kirch, 2014:113–14). Following this, from A.D. 1615 all of the newly constructed temples are located on or near the coast. The major phase of inland temple construction is consistent with the hypothesis of Kirch and Sharp (2005) that the Maui rulers who first consolidated the island-wide kingdom imposed a system of agricultural temples to control production and extract tribute from the zone of intensive cultivation.

4. Discussion

The expanded sample of 46 ^{230}Th dated coral offerings from 26 *heiau* sites in Kahikinui indicates that a major phase of temple construction commenced in southeast Maui in the second half of the sixteenth century and continued through the seventeenth century. This temporal pattern is evident whether one considers coral offerings from surface contexts or from architecturally integral contexts (Fig. 5). These new data support the hypothesis presented by Kirch and Sharp (2005) that a rapid phase of temple building was initiated by the successive Maui Island rulers Pi'ilani, Kiha-a-Pi'ilani, and Kamalalawalu, whose reigns are calculated on the basis of royal genealogies to have spanned the period from ca. A.D. 1570–1610 (Kirch, 2010, Table 3.1). According to Hawaiian traditions (Fornander, 1878; Kamakau, 1961) these rulers consolidated several formerly independent chiefdoms into a single, island-wide polity as part of a process of archaic state formation (Hommon, 2013; Kirch, 2010, 2013).

Kolb (2006) argued on the basis of radiocarbon dates from Maui temples that the relatively short period of temple construction indicated by the initial set of ^{230}Th-dated corals reported by Kirch and Sharp (2005) did not accurately reflect the temporal pattern of temple construction. Rather, Kolb advocated a "more probable explanation" that the tight temporal clustering of the coral dates "represent a localized pattern of temple *use* … such as a district-wide temple remodeling event or religious celebration" (2006:663). Kolb's alternative interpretation can now be confidently rejected based on the expanded sample of 46 dates from both surface and architecturally integral contexts.

A comparison of available ^{14}C and ^{230}Th dates from Kahikinui temples is instructive. Fig. 7 is an Oxcal-generated plot of the

Table 2
Temple sites (excluding fishing shrines) with attributes of morphology, orientation, and location. Temples are ordered by the age of the oldest coral date from each site (i.e., that most closely approximating initial construction).

Site no.	Oldest U/Th date A.D.	Morphology				Orientation				Location	
		Notched	Square	Elongated double-court	Other form	N Facing	NE facing	E facing	Other orientation	Coastal	Inland
LUA-4	1696	X				X				X	
AUW-9	1692	X				X				X	
KIP-307	1643	X				X				X	
Kou	1634				X				X	X	
KIP-275	1625		X					X		X	
KIP-273	1618	X						X		X	
LUA-29	1615	X					X			X	
NAK-29	1603	X					X				X
KIP-405	1601				X			X			X
ALE-140	1592	X					X				X
LUA-3	1590		X			X				X	
WF–AUW–359	1588	X						X			X
KIP-1010	1580	X				X					X
KIP-567	1575		X				X				X
KIP-414	1574				X			X			X
KIP-728	1572			X							X
ALE-4	1555	X				X				X	
AUW-6	1547				X	X				X	
WF–AUW–338	1328	X				X					X
KIP-1	1325			X				X			X

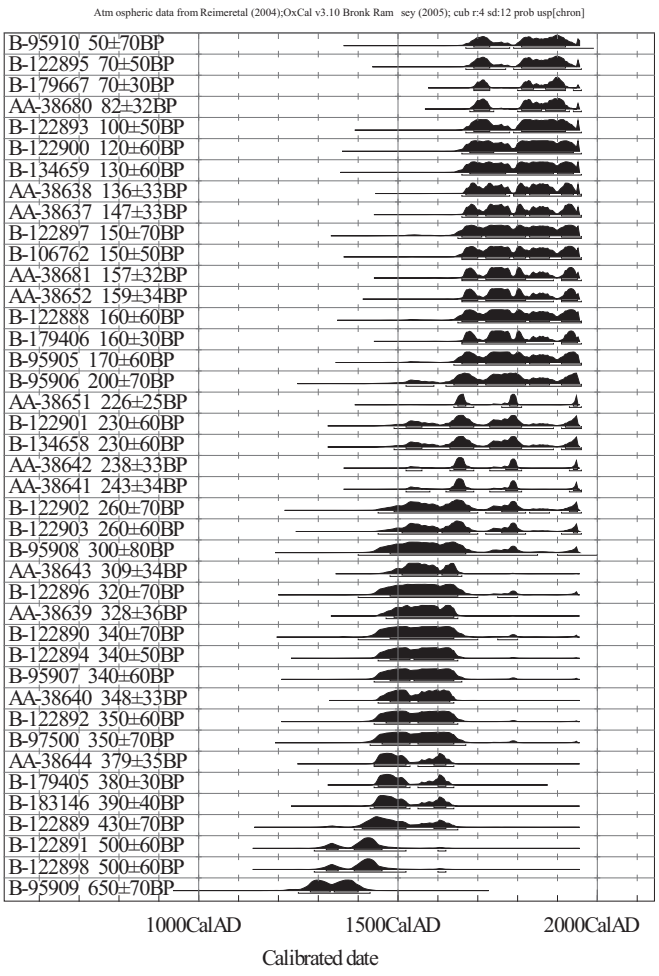

Fig. 7. Oxcal generated plot of 41 radiocarbon dates from Kahikinui temple sites.

calibrated age ranges for 41 radiocarbon dates from 31 temple sites in Kahikinui, including 24 samples from Kahikinui reported by Kolb (2006, Table 1) and an additional 17 dates obtained by Kirch (unpublished data). As is typical of radiocarbon dates for this late time period, the probability distributions exhibited in Fig. 7 are frequently bi- or multi-modal, with multiple possible calendar ages, and with 2σ ranges two or more centuries making precise temporal interpretations problematic. Nonetheless, with only three exceptions all of the radiocarbon samples post-date A.D. 1400. Sixteen radiocarbon dates have probability distributions spanning the period from about A.D. 1550 to 1650, making them entirely consistent with the more precise suite of ^{230}Th coral dates indicating a major phase of temple construction during the late sixteenth and seventeenth centuries. The remaining 22 radiocarbon dates post-date A.D. 1650, demonstrating continued use (rather than construction) of temples during the final period prior to European contact. In short, rather than contradicting the temporal pattern indicated by the ^{230}Th-dated corals, the ^{14}C corpus from Kahikinui is consistent with and confirms this pattern when ^{14}C dates potentially subject to in-built ages effects are discounted.

What of the three radiocarbon dates in Fig. 7 that pre-date A.D. 1500? The oldest (B-95909) is from site 1386 (Koholuapapa Heiau) in Auwahi. Although we searched for coral samples on this temple none were found; it thus remains dated only by the radiocarbon method. However, in addition to the oldest "basal" date of 650 ± 70 B.P. reported by Kolb (2006, Table 1), there is a second "basal" date from the same site of 300 ± 80 B.P. with calibrated ranges of A.D. 1437–1690, 1729–1810, 1924–1952. The lack of consistency in these two "basal" dates suggests that the older one probably represents either an "old wood" effect and/or a period of pre-temple land use such as forest clearance for gardening. The younger age with its highest probability intercept (85.8%) of A.D. 1437–1690 is consistent with the pattern of temple building revealed by the ^{230}Th-dated corals.

Sample B-122898 (500 ± 60 B.P.) comes from upland temple site 4365 (KIP-410), also reported by Kolb (2006, Table 1) to be from a "basal" context. This has a highest probability calibrated age range of A.D. 1378–1496. Again, we searched unsuccessfully for coral offerings on this temple. While we cannot rule out the possibility that temple KIP-410 was constructed in the fifteenth century, it is also possible that the single radiocarbon sample represents either pre-temple land use or was from wood charcoal with an in-built age factor.

Finally, sample B-122891 (500 ± 60 B.P.) was obtained by Kolb from site 181 (KIP-1); this also has a highest probability age range of A.D. 1378–1496 (74.1%), and lower probability ranges of A.D. 1298–1371 (24.4%), 1508–1510 (0.1%), and 1601–1615 (1.4%). Here we were successful in finding one coral offering (with a slightly rounded branch tip, KIP-1-CS-1, see Table 1), in a surface context. This coral sample yielded a corrected age of A.D. 1325 ± 3, which overlaps with the oldest possible age range of radiocarbon date B-122891. Given the agreement between the radiocarbon and coral dates, we cautiously suggest that temple KIP-1 was initially constructed in the fourteenth century, prior to the main phase of temple expansion. Site KIP-1 is of the elongated, double-court type which may be an earlier form of temple.

Our sample includes three other coral specimens that pre-date the main phase of temple construction. As described in Section 3.3.10, two of these three come from the Kou temple complex in Kaupō, a location with associations to early Polynesian settlement in the Hawaiian historical traditions. The main temple at Kou, however, with its impressive standing architecture, dates to a relatively late time period. One other sample from WF-AUW-338 yielded a corrected date of A.D. 1328 ± 3. Because this was in surface context, we cannot be certain that it dates the construction of this small, notched *heiau* in the Auwahi uplands. However, the age range is nearly identical to that from site KIP-1, and may be a second indication of early ritual activity in the Kahikinui uplands.

To be clear, we do not disagree with Kolb's contention that the development of the Maui temple system began in some sectors of the island as early as A.D. 1200. Many of the earlier dates reported by Kolb (2006) come from the Wailuku, Kula, and Hāna districts of Maui where environmental conditions were more favorable, inviting early settlement; these regions are noted in the Hawaiian traditions as having been centers of early chiefdom development (Kamakau, 1961; Kirch, 2010, 2013). Arid Kahikinui district, however, is the most marginal part of Maui for dryland farming and a large corpus of radiocarbon dates from habitation sites indicates that the district did not begin to be intensively farmed until after A.D. 1400 (Kirch, 2014). Our contention is that the population of this marginal district was not incorporated into the emerging Maui Island archaic state until the late sixteenth century, and that this political transformation is materially signaled by the major phase of temple construction now clearly indicated by both the samples of ^{230}Th and ^{14}C dates from Kahikinui temples.

It is also instructive to compare our results of ^{230}Th dating of Kahikinui temples with a similar set of dates obtained from another Polynesian locality, that of Mo'orea Island in the Society Islands archipelago. Sharp et al. (2010) obtained 47 ^{230}Th dates on corals from 22 temples (*marae*) on Mo'orea, including three large coastal temples associated with the island's highest-ranking elites, and 19 temples in the interior of the 'Opunohu Valley. In the Mo'orea

temples, the dated corals were used primarily as architectural elements such as facades in the altar (*ahu*) platforms. The suite of ^{230}Th dates from these corals indicated that the Mo'orea temples were constructed within a relatively short period of about 140 years, from A.D. 1620–1760, during which temple architecture underwent considerable elaboration. This time period is associated in Society Islands oral traditions with the emergence of sociopolitical complexity, increasing competition between chiefly lineages, and the spread of the 'Oro war cult. Thus both the Kahikinui, Maui temple dates and those from Mo'orea Island attest to similar phases of rapid temple construction (in each case less than 150 years in duration) linked to periods of major sociopolitical transformation—the emergence of an archaic state in Maui, and intense chiefdom competition in Mo'orea.

5. Conclusions

An expanded sample of 46 ^{230}Th-dated coral offerings from 26 temples in Kahikinui district of Maui Island confirms a major phase of temple construction beginning in the second half of the sixteenth century and continuing through the seventeenth century. This rapid expansion of temple construction is largely corroborated by a corpus of 41 radiocarbon dates from 31 temples; however, the ^{14}C dates lack the same degree of temporal precision as the coral dates. This phase of temple expansion correlates well with indigenous Hawaiian traditions regarding the consolidation and expansion of the Maui polity at the end of the sixteenth century and continuing on into the seventeenth century, under the control of an elite lineage founded by the ruler Pi'ilani (Kamakau, 1961).

Although the majority of the dated temples were built after A.D. 1550, one and possibly two *heiau* pre-date the main phase of temple building, indicating some ritual activity in the district as early as the fourteenth century. Also, branch coral offerings were in use at the site of Kou in Kaupō district as early as the end of the eleventh century; Kou is a location tied in Hawaiian traditions to the first Polynesian settlement of the islands (Kamakau, 1991:112).

In addition to demonstrating a major phase of temple construction in Kahikinui district, the high precision temporal analysis afforded by ^{230}Th dating demonstrates that several different architectural forms, as well as temple orientations, were in use simultaneously throughout the sixteenth and seventeenth centuries on Maui. The new Maui temple chronology also demonstrates how a major phase of temple construction coincided with and was linked to the emergence of an archaic state over a period of about one and a half centuries.

Acknowledgments

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2014.09.025.

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